Application of an Ocean Model and its Adjoint for Global Data Assimilation and Sensitivity Analysis

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For more info: http://ecco.jpl.nasa.gov/odap/html/index.html and http://eyre.jpl.nasa.gov/las/main.pl or contact tlee@pacific.jpl.nasa.gov

Summary:
The MIT Ocean General Circulation Model and its adjoint are applied to (1) global data assimilation to estimate the four-dimensional state of the ocean and (2) sensitivity analysis to elucidate response of ocean current to wind forcing.
Model: domain: 75 °S-75 °N; resolution: 1°x0.3 °in tropics, 1°x1° in extra-tropics, 46 vertical levels, 10-m thickness above 150 m.
Adjoint: constructed using an automatic differentiation software (TAMC/TAF); computes sensitivity of a dependent variable (of the model state) to independent variables.

(1) Global Data Assimilation:

Objective: to find a dynamically consistent solution that is close to observations.
Application example: mixed-layer heat budget in the eastern equatorial Pacific associated the 1997-2000 ENSO events.

Dependent variable:

J = Deviation of model sea level anomaly from satellite data (TOPEX/Poseidon altimeter) + Deviation of estimated surface fluxes from prior values (NCEP reanalysis) + Deviation of mean temperature and salinity from climatology (Levitus)

Independent variables:

X = Initial temperature, salinity, and surface fluxes (wind stress, heat, and freshwater fluxes)

Optimization:

Adjoint sensitivity $\partial J / \partial X$ is used to minimize J by adjusting X, subject to constraints by nonlinear model dynamics.

Assessment of skill in fitting sea level data

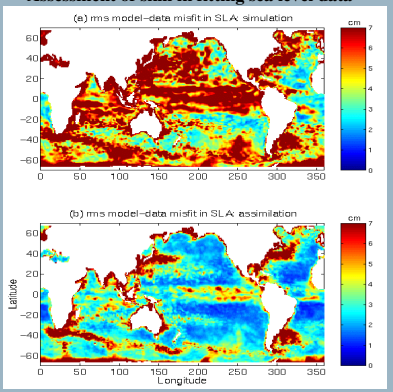

Fig. 1 The assimilation significantly reduces model-data misfit in sea level, especially in the tropics.

Validation by comparison with independent data

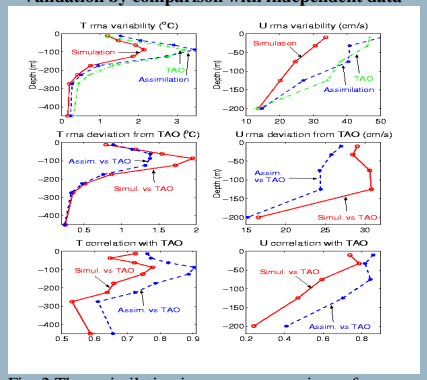

Fig. 2 The assimilation improves comparison of temperature and zonal velocity with in-situ data in the tropical Pacific (TOGA-ATO moorings).

Application to heat budget analysis

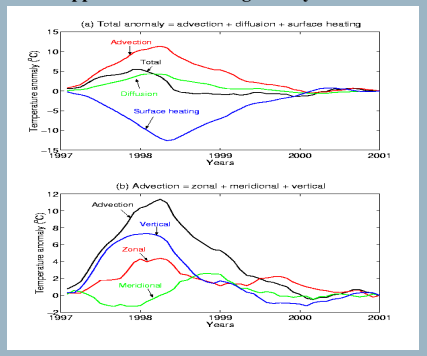

Fig. 3 Interannual change of mixed-layer temperature in 210-270 °E, 5°S-5°N is assisted by advection and diffusion, but opposed by surface heat flux. Vertical advection is more important than horizontal and meridional advection.

(2) Sensitivity analysis:

Objective: to examine sensitivity of model ocean current to wind forcing and to elucidate the underlying processes.
Application example: local and remote wind forcing of interannual transport of the Indo-Pacific throughflow (ITF).

Dependent variable:

$\overline{V}$= Annual mean depth-integrated ITF transport

Independent variables:

$\tau(x,y)= (\tau_x, \tau_y)$ Annual mean zonal and meridional wind stress

Adjoint sensitivity:

$s(x,y) = \partial \overline{V} / \partial \tau = (\partial \overline{V} / \partial \tau_x, \partial \overline{V} / \partial \tau_y)$ reflects sensitivity of annual mean ITF transport to annual mean wind stress (Fig. 4).

Sensitivity of ITF transport to wind stress

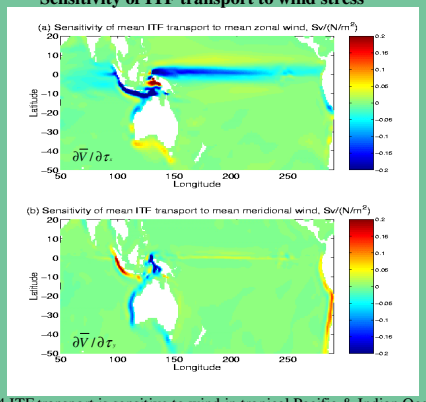

Fig. 4 ITF transport is sensitive to wind in tropical Pacific & Indian Ocean (esp. off Java), south and west of Australia, and off South America.

Contribution of interannual wind anomaly:

Projection of interannual anomaly of wind $\tau(x,y,t)'$ to adjoint sensitivity gives contribution of interannual wind anomaly to interannual ITF transport anomaly $c(x,y,t)' = s(x,y) * \tau(x,y,t)'$ (temporal r.m.s. map of $c(x,y,t)'$ is shown in **Fig. 5**).

Integrating $c(x,y,t)'$ over various region to evaluate relative contribution of regional wind anomaly to ITF transport

$V(t)' = \int c(x,y,t)' \, dx \, dy$

Fig. 6 shows example for Indian vs. Pacific Oceans.

r.m.s. spatial contribution of wind to ITF transport

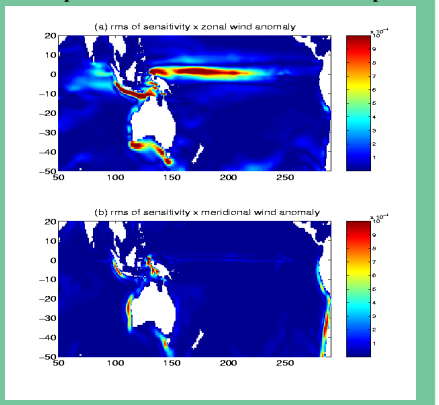

Fig. 5 r.m.s. map of spatial contribution of zonal (a) and meridional (b) wind anomaly to ITF transport anomaly.

Counteracting roles of Indian and Pacific Ocean wind

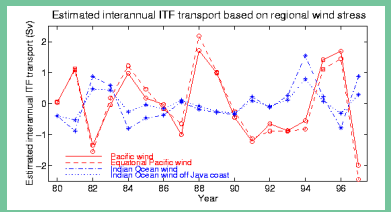

Fig. 6 Contribution of Indian Ocean wind to ITF transport opposes that of Pacific Ocean on interannual time scale. This counteracting effect is attributed primarily to oscillation of the Walker circulation.